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KØBENHAVN
C. A. REITZELS FORLAG
BIANCO LUNOS BOGTRYKKERI
1929

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BY

AAGE J. C. JENSEN

KØBENHAVN
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I. The material on which this investigation is based.

A. The fishery yield and its applicability as an expression for the size of the stock.

The investigations carried out by J. P. JACOBSEN and A. C. JOHANSEN on the quantity of cod fry in Danish waters and on the transportation of eggs and pelagic larvae by the current proved that it is beyond doubt that the Kattegat, the Belt Sea, and the true Baltic have their own indigenous stock of cod besides the stock immigrating from the Skagerak in the winter months.[1]

Marking experiments on cod have been carried out within Skagen (the Skaw) in 1906, 1907, 1912, and 1913. Altogether in these years 1273 cod were marked in different localities in the Kattegat, the Belts, and the western Baltic.[2] It is clear from the experiments that cod under c. 60 cm. in length may be described as fairly stationary. The largest of the cod marked seemed on the other hand to evince an inclination to make longer migrations. Of 200 marked cod however, varying in size from 70 cm. to 106 cm., only 16 were recaptured and since the result of the experiments does not point in the same direction we cannot draw any reliable conclusions from them as to the migrations of the larger cod. Only 4 of these cod were caught more than 30 nautical miles from the spot where they were marked.

The marking experiments give us therefore very little information as to the extent of the immigration of the larger cod which is supposed to take place into the Sound and the Belts in the autumn and winter months.

Racial investigations on cod have been carried out by JOHS. SCHMIDT also in these waters. They have shown that the total stock of cod of the Baltic east of Bornholm is indigenous. The best racial character (average number of rays in the second dorsal fin) gave for the Baltic west of Bornholm, the Belt Sea and the Kattegat values intermediate between the values found for the Baltic east of Bornholm and those found for the North Sea.[3] From the facts published it is not to be seen in what degree it is possible from the results of this investigations to deduce how great a part an immigration in the winter months of cod from the Skagerak constitute in the stock found in the Kattegat, Belts and Sound beside the numbers of cod indigenous to these waters.

The percentage of cod recaptured in the course of the first year after marking affords evidence of how intensively the fishery is carried on in proportion to the size of the existing stock.

Of the total 1273 cod marked in these waters, 19.1 per cent. were recaptured in the course of the first year, the figures relating to recapture being apportioned between the different size groups as follows:

Length in cm	20—49	50—69	70—106
Number marked	657	416	200
Percentage recaptured in the first year	21	21	8

[1] J. P. JACOBSEN and A. C. JOHANSEN: Remarks on the changes in specific gravity of pelagic fish eggs and the transportation of same in Danish waters. — Medd. f. Komm. f. Havunders. Ser. Fiskeri. Bd. III Nr. 2. 1908.

[2] A. C. STRUBBERG: Marking experiments with cod (*Gadus callarias* L.) in Danish waters 1905—13. — Medd. f. Komm. f. Havunders. Ser. Fiskeri. Bd. VII Nr. 1. 1922.

[3] JOHS. SCHMIDT: Racial Investigations. — Cons. Perm. Internat. Rapports et Procés-Verbaux des Reunions. Vol. LIV. 1929.

If the intensity of the fishing is fairly constant the recapture of about one fifth of the stock in the course of a year must show (cp. Table 1), in view of the great variations from year to year in the total yield[1] of the cod fishery, that these variations in the yield can be utilized as an expression for the variations in the size of that cod stock on which the fishery can levy toll.

The yield of the fishery is dependent on the number of implements employed in fishing. The use made of the implements frequently depends on the price per kilogram of fish, the intensity of fishing (and thereby the yield by weight of the fishery) being namely stimulated by high prices whilst low prices bring about a less intensive fishery.

It will be seen from Table 1 that the number of fishing implements has not varied in the same way as the yield of the fishery and cannot be the main cause of the variations in the yield, and moreover that it is also not the price obtained per kilogram which has determined the fishery yield.

Table 1. Yield in metric tons of the Danish cod fishery within Skagen, number of fishing implements and price per kilogram for cod.

	Yield of the fishery landed in					Number of implements												Price per kg. in Oere		
						Kattegat				Belts				True Baltic						
	Kattegat	Belts[2]	Western Baltic[2]	The Sound	True Baltic	Cod weels	Danish seine	Otter seine	Lines	Cod weels	Danish seine	Otter seine	Lines	Cod weels	Danish seine	Otter seine	Lines	Kattegat	Belts	True Baltic
1909...	1261	2304	64	551	1119	6910	1847	?	?	45855	341	?	?	220	1	?	?	22.7	20.9	14.7
1910...	2135	3201	81	1166	793	6708	1748	?	?	56738	389	?	?	270	8	?	?	20.3	19.6	17.3
1911...	2179	3361	85	1637	428	6153	1880	?	?	41583	464	?	?	130	0	?	?	17.8	18.7	18.3
1912...	2148	3864	76	1604	453	7311	1996	3	28869	41493	527	441	19865	40	1	56	4940	17.7	18.0	16.9
1913...	3046	2881	113	1091	422	6910	1985	4	26102	38162	479	774	22239	90	2	61	3870	21.8	20.9	19.7
1914...	2868	2496	66	972	622	7225	2059	16	30575	38036	476	742	18958	20	5	59	4895	23.9	24.0	18.6
1915...	3781	3371	134	746	1226	6517	2054	35	18530	38233	457	801	25408	0	3	70	5970	28.6	28.6	20.6
1916...	4518	3992	187	815	766	7868	1883	73	18655	41925	311	863	21639	10	3	32	4780	55.7	50.8	48.9
1917...	3245	3648	154	667	311	5796	2146	89	24113	43219	305	813	18984	106	6	92	4645	51.2	49.3	38.1
1918...	2595	4435	302	770	253	4913	2103	103	19446	36746	267	874	17607	120	0	81	5450	56.6	53.4	56.4
1919...	4134	6360	321	1956	570	5184	2259	237	21015	36795	312	1219	18603	20	2	94	5860	48.6	46.3	41.8
1920...	4352	6341	201	1745	944	4349	2345	238	20544	43364	351	1188	20943	110	4	89	5790	43.0	41.3	36.2
1921...	4061	5777	154	1350	744	4854	2179	190	25758	40206	331	1226	17097	50	10	98	7690	32.1	29.3	28.2
1922...	4406	4873	162	1268	635	5070	2396	234	25390	35227	325	1521	15911	90	24	103	7525	23.9	19.6	23.9
1923...	5666	5448	138	1532	659	5260	2377	205	28561	31832	321	1354	14454	100	96	169	7195	25.5	22.5	25.9
1924...	5629	4806	225	1200	943	4686	2431	186	27297	29244	306	1348	17761	170	112	422	7810	30.6	27.3	36.0
1925...	6066	5782	232	1313	1040	4341	2517	193	28502	26528	316	1397	18426	110	110	558	10070	29.5	24.9	30.1
1926...	6483	7075	275	1497	1106	3596	2537	248	29855	26576	302	1386	18845	150	104	604	16865	22.2	16.7	23.6
1927...	6447	7016	293	1701	1076	2965	2704	242	32325	24394	350	1363	18211	40	100	620	9955	17.6	14.0	19.8
Mean..	3948	4581	172	1241	743															

As fishing for cod in the Danish waters within Skagen is carried on fairly intensively with many different implements, especially with pound-nets, weels, Danish seines, otter seines, nets, lines, and tin-baits, the variations from year to year in the total yield of the fishery can scarcely result from the presence of a greater or less part of the stock in these waters outside the reach of the fishing implements.

We can therefore assume that the variations from year to year in the total fishery yield are to a considerable degree a measure for the variations in size of the total cod stock in these waters. We do not know however, as pointed out above, how large a portion of this stock is stationary in these waters

[1] By the total yield or the yield is always meant in this paper the aggregate yield by weight of the fishery in question in the course of the year.

[2] For the years after 1920 (the reunion) the Danish catch from Sønderjylland is omitted for the sake of comparison with the yield before that year.

and how large a portion is only present as visitors in the autumn and winter. The marking experiments showed however that not a small portion of the stock may be considered as stationary.

As regards herring, the racial investigations which have been carried out in such large numbers by A. C. JOHANSEN have shown that the races of herring which are found in the Kattegat and the Belt Sea seem never, so far as a number of them are concerned, to leave these waters.[1]

Some of the herring races which spawn in the Kattegat are encountered in the Skagerak. The winter-spawning herring in the Kattegat thus constitute a considerable part of the young herring which are captured by the great Bohuslän herring fisheries. Also the autumn herring and the spring herring in the Kattegat are caught in the eastern Skagerak.[2] In the most northerly portion of the Kattegat may be found, at any rate in certain years, a considerable number of North Sea Bank herring which enter the eastern Skagerak and the adjoining waters as spent herrings in the autumn and winter months. These herring are however found for the most part in the north-eastern portion of the Kattegat and have up till now only played a very small part in the yield of the Danish herring fisheries.

We possess no measure for the total yield of the herring fishery in relation to the size of the herring stock in our waters.

It will be seen from Table 2 that it is not the variations in the number of fishing implements which determine the variations from year to year in the total catches of the herring fisheries employing nets, pound-nets, and drift-nets, nor is it the prices which can be obtained for the herring.

Table 2. Yield in metric tons of the Danish herring fishery with nets and pound-nets and with drift-nets within Skagen, number of fishing implements and price per kilogram for herring.

	Yield of the fishery landed in										Number of implements						Price per kg. in Oere		
	Kattegat		Belts[3]		Western Baltic[3]		The Sound		True Baltic		Kattegat		Belts		True Baltic		Kattegat	Belts	True Baltic
	Nets and pound-nets	Drift-nets	Nets and pound-nets	Drift-nets	Nets and pound-nets	Drift-nets	Nets and pound-nets	Drift-nets	Nets and pound-nets	Drift-nets	Pound-nets	Herring-nets	Pound-nets	Herring-nets	Pound-nets	Herring-nets			
1909	1445	1578	3298	1855	109	286	24	484	636	1987	717	17233	1257	18303	144	15972	15.3	18.3	14.5
1910	970	1096	3355	1360	50	352	87	279	461	1261	682	17432	1366	16337	161	17016	17.3	16.6	20.1
1911	5077	894	4713	1658	297	146	240	206	467	1322	559	15829	1430	15800	214	16579	9.0	14.9	19.6
1912	4318	797	4827	752	155	136	345	730	158	2689	732	14257	1675	15600	320	19819	12.0	18.3	11.1
1913	2316	1165	8509	1969	232	255	467	528	678	2287	726	14175	1892	15046	411	17565	11.3	10.4	13.6
1914	1937	897	9645	347	312	20	267	172	1160	1326	754	14190	1845	13893	379	17970	14.5	10.7	17.8
1915	1364	651	8914	598	84	47	598	96	1172	861	729	14703	1977	14472	394	17925	18.2	19.4	29.0
1916	3832	475	7438	1245	808	126	1805	554	1968	3668	719	14621	2130	16143	484	18335	44.6	52.1	47.6
1917	2032	2294	4464	1111	599	58	458	1983	2916	2479	810	15123	2228	18014	490	17620	32.0	50.7	29.9
1918	1130	2302	4591	1793	358	254	1178	890	3948	2253	728	16436	2051	16979	462	17240	53.6	47.7	45.6
1919	2728	1179	3644	1508	386	127	1142	1924	1935	2877	785	15631	1930	18010	415	17474	53.3	55.3	45.4
1920	931	625	2905	1066	125	180	661	1044	1708	2157	791	15055	1848	19729	391	17650	62.2	50.3	46.2
1921	1072	497	1173	458	113	58	153	198	1477	2627	834	15062	1849	19315	329	18820	52.8	48.6	35.3
1922	1009	508	1187	572	66	90	102	183	545	2167	809	15180	1791	16972	303	18570	41.5	33.4	23.1
1923	1939	1419	1829	1511	53	138	62	92	954	2055	811	14880	1715	15004	328	20120	22.4	22.4	31.8
1924	1633	3111	1853	2578	139	158	154	129	1324	1392	844	15480	1699	15916	272	21980	33.2	35.2	38.0
1925	1791	2480	1604	1338	47	144	160	163	507	1934	860	15675	1792	16113	381	23190	32.5	32.7	37.8
1926	1019	1956	1252	987	51	186	390	156	621	1050	866	14795	1825	15488	414	22880	29.6	26.0	34.0
1927	1729	1708	2029	952	22	120	492	228	1383	1646	905	15490	1867	16381	416	23080	23.1	19.8	26.5
Mean	2014	1349	4065	1245	211	152	462	528	1264	2002									

[1] A. C. JOHANSEN: On the Migrations of the Herring. — Journal du Conseil. Vol. II. No. 1. 1927.

[2] A. C. JOHANSEN: Über die Winterheringe des Kattegats. — Wissensch. Meeresunter. N. F. Helgoland. XV Festschrift für Fr. Heincke, Nr. 12. 1923.

[3] See note, table 1.

In view of the fact that the herring fishery is carried on intensively in most of the localities in our waters and in view of the restricted extent of the waters it may be assumed that the yield of the herring fishery is dependent to a high degree on the size of the stock. Nets and pound-nets, drift-nets, purse-seines and seines are principally employed in the herring fishery in these waters. Each of these implements is chiefly instrumental in capturing certain definite size-groups. The purse-seine fishery thus captures as a rule a larger quantity of small and younger herring than the others, the herring taken by the pound-nets are on an average somewhat older and greater, and of these implements it is the drift-net which captures on an average the largest age-group.

Of these fisheries the drift-net herring fishery was carried on very irregularly during the years 1914—18, being greatly interfered with by the presence of mines and the lack of oil fuel.

In the waters within Skagen as far as Bornholm the yield of the Danish fishery is specified according to the fishing implements employed.

As regards Denmark the vast majority of herring are caught with nets, pound-nets, and drift-nets. The variations from year to year of the catches with purse-seine and seine depend to a great degree on how much these implements are used for fishing in the year in question.

If for the period 1909—27 (excluding the years 1914—18 in the case of the drift-net fishery) we calculate the correlation coefficient[1] between the catches with the nets and pound-nets and the catches with the drift-nets in the previous, the same, the following, and the subsequent year we obtain:

	Area.....	Kattegat		The Belts		Western Baltic		The Sound		True Baltic	
		r	σ_r	r	σ_r	r	σ_r	r	σ_r	r	σ_r
Yield of the net and pound-net fishery correlatet with yield of drift-net fishery	previous year...	—0.16	0.27	0.13	0.27	0.50	0.21	0.55	0.20	0.09	0.28
	same year.....	—0.14	0.26	0.35	0.23	—0.09	0.27	0.82	0.09	0.35	0.23
	1 year later.....	—0.10	0.28	0.06	0.28	—0.02	0.28	0.82	0.09	0.62	0.17
	2 years later....	—0.09	0.29	—0.17	0.28	—0.01	0.29	0.28	0.27	0.39	0.25

It will be seen that in the case of the Sound it is established that a large yield from the net and pound-net herring fishery is normally followed by a large yield from the drift-net herring fishery both in the same and the following year, and moreover in the case of the true Baltic that a large yield from the net and pound-net herring fishery is followed by a large yield from the drift-net fishery in the immediately following years. The explanation of this may be found in the fact that the herring caught with drift-nets are on an average a little older than those caught with the pound-nets. In the Kattegat and the Belts the yield of the drift-net herring fishery is considerably less than that of the net and pound-net herring fishery and is presumably to a corresponding degree less representative of the size of the stock.

B. The reliability of fishery statistics.

The catches of the Danish cod and herring fisheries within Skagen have been arranged in the Fiskeri-Beretning since 1909 according to the water-areas: the Kattegat, the Sound, the Belts, the western Baltic and the true Baltic.

Since 1909 the information afforded by the statistics, and especially in regard to the large landing places for fish, has been considerably more accurate than in previous years as at that date the keeping of fishery journals was instituted at the six largest landing places for all decked vessels over 5 tons gross; these journals were kept either by the skipper of the vessel or by an official of the Fishery Control Board[2]. As regards the remaining vessels the catches had to be entered on monthly schedules. Previously

[1] Pearson's formula $r = \frac{\Sigma p \alpha_x \alpha_y}{\sqrt{\Sigma p' \alpha_x^2 \Sigma p'' \alpha_y^2}}$ is used.

[2] A. C. Johansen and E. Neergaard-Møller: Biological-statistical Report on the Danish Sea-Fishery in 1909. Medd. f. Komm. f. Hav unders. Ser. Fiskeristatistik 1912. p. 5.

the catches had only been computed once a year in the case of a large number of vessels. A further improvement was put into practice in 1912, considerable alterations then taking place with regard to the collection and working up of the material. From the beginning of 1912 the collection and working up of the statistical material relating to fisheries was transferred directly to the office of the Fisheries Inspector (later Director of Fisheries), a greater uniformity being thereby attained in the collection and working up of statistics [1].

II. The relation between the cod and herring stocks.

The cod has been looked upon from olden times as one of the worst enemies of the herring. It is well-known that HUXLEY sought to prove on the ground of probability from the total catches of cod and herring how little the depredations of man signified to the herring stock in comparison with the destruction to which it was exposed from the cod species and particularly the cod.

Also in Danish waters the herring forms a part of the food of cod and there is an a priori possibility that the cod stock can reduce the contemporary herring stock to such an extent that it can be noticed in the yield of the herring fishery.

According to H. BLEGVAD, the herring is especially consumed by the large cod which in the autumn find their way into the *zostera* zone and are often caught in weels. In the Danish waters within Skagen and in the Limfjord 912 cod in all, 2.5—92 cm. in length, were examined and of these *clupea* constituted 197.7 grams out of a total of 11335.5 grams of stomach contents [2]. According to ERIK M. POULSEN, herring are consumed by cod of over c. 30 cm. length. In the Belt Sea were found herring in 18 of 247 individuals over 30 cm. in length, and in the Baltic proper in 5 of 68 individuals. Herring were the fish most frequently observed in these cod.

As is clear from the above, it must be assumed that a considerable part of the cod stock and the herring stock in the Danish waters within Skagen is fairly stationary and that so far as the herring stock is concerned this must be assumed to be so to a higher degree in the Belts than in the Kattegat. The Belts are the only Danish waters where practically the entire fishery is carried on by Danish fishermen and where the entire yield of the herring fishery can be apportioned according to the implements used. Furthermore of the Danish waters within Skagen the Belts provide the Danish fishery with the largest total catches of both cod and herring.

As regards herring we must consider two different fisheries as separate, viz. the net and pound-net fishery and the drift-net fishery (cp. p. 6). It may in general be assumed that of the two fisheries the one which has afforded the largest yield is most representative of the size of the stock. In the Kattegat and the Belts the net and pound-net fishery afforded a greater yield in the period in question than the drift-net fishery, whilst the two fisheries gave on an average about the same yield in the western Baltic and in the Sound. In the true Baltic the drift-net fishery produced the larger yield of the two fisheries (cp. Table 2, p. 5).

A. The cod fishery compared with the net and pound-net herring fishery.

a) The Belts. If we compare the total yield of the cod fishery in the Belts with the total yield of the net and pound-net herring fishery in this area, it will be seen (Fig. 1) that the yields of the two fisheries vary inversely, especially when the yield of the cod fishery in any one year is compared with that of the herring fishery in the following and the subsequent year.

[1] F. V. MORTENSEN: Fiskeri-Beretning for Aaret 1912. 1913, p. 1.

[2] H. BLEGVAD: On the Food of Fish in the Danish Waters within the Skaw. Report of the Danish Biol. Stat. XXIV.

By calculating the correlation coefficient between the catches of cod and of herring caught with nets and pound-nets we obtain:

		for period 1909—27	for period 1912—27
Total catches of cod correlated with total catches of herring with nets and pound-nets in the Belts	same year	$r = -0.68$; $\sigma_r = 0.12$	$r = -0.82$; $\sigma_r = 0.08$
	1 year after	$r = -0.72$; $\sigma_r = 0.11$	$r = -0.84$; $\sigma_r = 0.08$
	2 years after	$r = -0.78$; $\sigma_r = 0.10$	$r = -0.80$; $\sigma_r = 0.10$
	3 years after	$r = -0.66$; $\sigma_r = 0.14$	$r = -0.66$; $\sigma_r = 0.16$

All these calculations thus give very large correlation coefficients. It will be seen however from the Fig. 1 that one cause which to a considerable degree contributes to the contrary movement of the two fishery yields being so strongly in evidence is the increase in the main of the cod fishery yield in

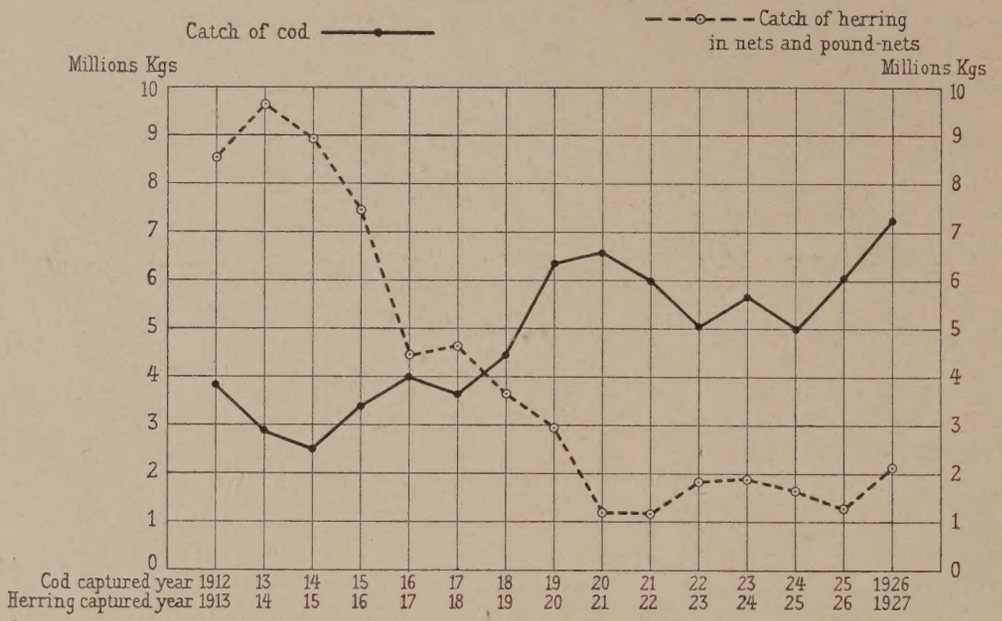

Fig. 1. Comparison for the Belts between yield of the cod fishery and yield of the herring fishery with nets and pound-nets one year after.

these years and the decrease in the main of the net and pound-net fishery yield. It is conceivable that the high values for the correlation between the yields of the two fisheries is principally due to the contrary movement in the main features of the two fishery yields. The yields of two fisheries can obviously vary inversely as to their main features throughout a period such as this without there consequently being a causal connexion of any kind between the variations in the two fisheries.

We must therefore seek to eliminate the effect of these great variations in the yields of the two fisheries in order to investigate whether they also vary inversely in details to such a degree that we may say that there is some causal connexion or other between these two fluctuations.

This can be done by calculating the differences of the yields of the two fisheries from normal yields of which that of the cod fishery increases and that of the net and pound-net fishery decreases throughout the period here under discussion, so that these normal yields may be taken as representing the effect of the changes which have taken place during these years in the main features of these two fishery yields.

In order to avoid a too subjective estimate, we determine the normal yield by constructing normal curves for the catch in these years so that the normal yield for the cod fishery shows a uniform percentile increase and the normal curve for the herring fishery a uniform percentile decrease. The normal

curve for the yield of the cod fishery is plotted so that the increase is from 3 million kg. in 1909 to 7.5 kg. in 1926 (i. e. 6.8 per cent. per annum). The normal curve for the yield of the pound-net fishery is plotted so that the decrease in the yield is from 10 million kg. in 1910 to 1 million kg. in 1927 (i. e. 17.9 per cent. per annum).

From the normal yield determined from these curves are then calculated the percentile catch anomalies. The normal curves are plotted so that both in the first and the second half of the period approximately as many positive anomalies are given as negative and so that the sum of the positive anomalies is approximately equal to the sum of the negative anomalies.

From calculations for the period following 1912 we obtain:

Percentile anomalies for the yield of the cod fishery correlated with the percentile anomalies for the yield of the net and pound-net fishery in the Belts (after eliminating the variations in the main features of the two fishery yields).

The same year	$r = -0.34$;	$\sigma_r = 0.22$
1 year after.....	$r = -0.63$;	$\sigma_r = 0.16$
2 years after.....	$r = -0.63$;	$\sigma_r = 0.16$
3 years after.....	$r = -0.19$;	$\sigma_r = 0.27$

A contrary movement in details can thus also be established in the variations of the two fishery yields during the period in question when the yield of the cod fishery is compared with the yield of the net and pound-net herring fishery in the following and the subsequent year.

b) Kattegat. It has been mentioned in the Introduction that herring indigenous to the Kattegat are regularly encountered in the Skagerak and that herring from the North Sea (the North Sea Bank herring) are sometimes encountered in the Kattegat.

The yield of the Kattegat herring fisheries for this reason alone cannot be regarded as an expression for the size of the herring stock in the Kattegat to the degree that the Belt Sea yield was for its herring stock. Moreover the fishing in the Kattegat is divided between Sweden and Denmark, and the Swedish share in the yield which is considerably larger than the Danish is not computed for this area alone but for the entire Bohuslän coast.

By calculating for the Kattegat the correlation coefficient between the total yield of the cod fishery and the total yield of the net and pound-net herring fishery we obtain:

		for period 1909—27		for period 1912—27	
Yield of the cod fishery correlated with the yield of the net and pound-net herring fishery in the Kattegat	same year	$r = -0.37$;	$\sigma_r = 0.20$	$r = -0.35$;	$\sigma_r = 0.22$
	1 year after....	$r = -0.37$;	$\sigma_r = 0.20$	$r = -0.29$;	$\sigma_r = 0.24$
	2 years after...	$r = -0.61$;	$\sigma_r = 0.15$	$r = -0.30$;	$\sigma_r = 0.25$
	3 years after...	$r = -0.41$;	$\sigma_r = 0.21$	$r = -0.09$;	$\sigma_r = 0.32$

It will be seen that also here there is a contrary, although less pronounced, movement in the two fishery yields when the yield of the cod fishery is compared with that of the net and pound-net herring fishery in the immediately following years, and the negative correlation coefficient also here reaches its highest value when the yield of the cod fishery for one year is compared with the yield of the herring fishery for the following and for the subsequent year.

c) The western Baltic. In the western Baltic larger quantities of cod and herring are caught by German fishermen than by Danish, during the period 1909—26 on an average 3 and 5 times as many respectively. It is therefore of interest to compare the total yield both for the Danish and the German fisheries.

The German herring fishery uses the purse-seine to a fairly large extent.

The average length of the herring at Travemünde caught with the purse-seine during the years 1920—22 was, according to Henking[1], as follows:

1920	18.35 cm.	(9080 individuals	measured)
1921	18.50 „	(5805 „	„)
1922	17.33 „	(4637 „	„)

The herring caught by the Danish herring fishery is on an average somewhat larger, so that the Danish and German herring fishery yields cannot be added together in this investigation.

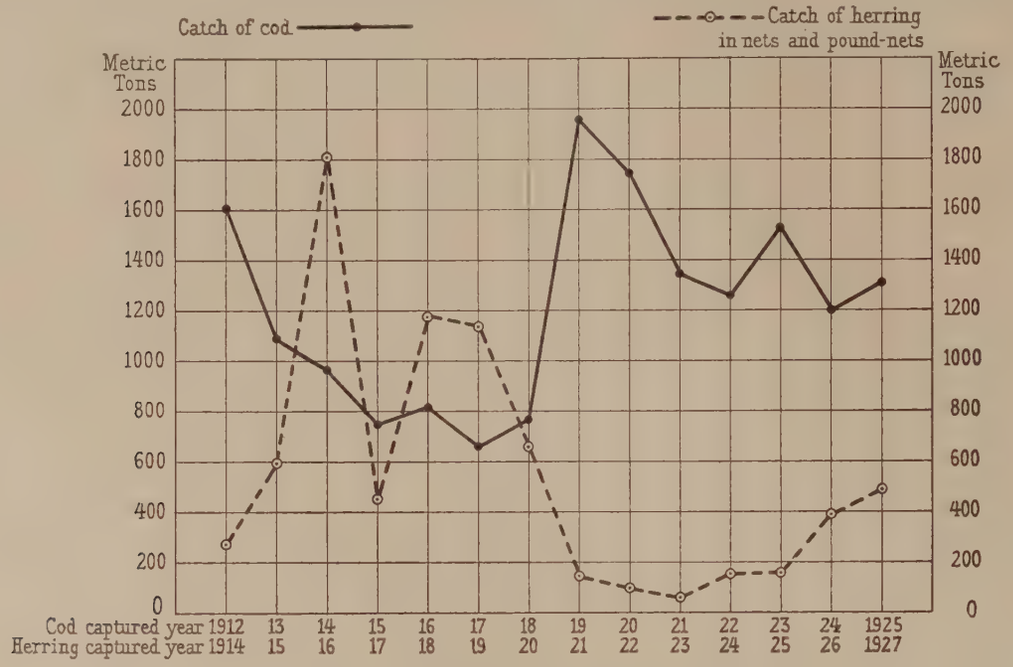

Fig. 2. Comparison for the Sound between yield of the cod fishery and yield of the herring fishery two years after.

By calculating the correlation coefficient between the yield of the cod fishery and that of the herring fishery in the western Baltic we obtain[2]:

		for period 1909—27	for period 1912—27
Yield of Danish cod fishery correlated with yield of Danish net and pound-net herring fishery	same year	$r = -0.21$; $\sigma_r = 0.22$	$r = -0.11$; $\sigma_r = 0.25$
	1 year after	$r = -0.31$; $\sigma_r = 0.21$	$r = -0.48$; $\sigma_r = 0.20$
	2 years after	$r = -0.59$; $\sigma_r = 0.14$	$r = -0.72$; $\sigma_r = 0.13$
	3 years after	$r = -0.53$; $\sigma_r = 0.18$	$r = -0.65$; $\sigma_r = 0.16$

		for period 1909—25
Yield of Danish-German cod fishery correlated with yield of Danish net and pound-net herring fishery	same year.....	$r = -0.38$; $\sigma_r = 0.21$
	1 year after	$r = -0.47$; $\sigma_r = 0.19$
	2 years after	$r = -0.79$; $\sigma_r = 0.10$
	3 years after	$r = -0.67$; $\sigma_r = 0.15$

[1] H. Henking: Die Ringwadenfischerei in der Lübecker Bucht im Frühjahr 1920. — Mitt. des Deutschen Seefischerei-Vereins 1920. S. 304 et seq.

id. Die Ringwadenfischerei im Frühjahr 1921. — Mitt. d. D. S.-V. 1921 S. 161 et seq.

id. Die Ringwadenfischerei im Frühjahr 1922. — Mitt. d. D. S.-V. 1922 S. 235 et seq.

[2] In view of the abnormal fishing conditions in Germany during the last years of the war the German fishery yields in 1917 and 1918 are omitted.

		for period 1909—25
Yield of German cod fishery correlated with the yield of the German herring fishery	same year.....	$r = -0.27$; $\sigma_r = 0.23$
	1 year after.....	$r = -0.35$; $\sigma_r = 0.23$
	2 years after....	$r = -0.63$; $\sigma_r = 0.17$
	3 years after....	$r = -0.51$; $\sigma_r = 0.17$

d.) The Sound. Also in the case of the Sound a connexion is demonstrable between the yield of the cod fishery and that of the net and pound-net herring fishery. A calculation of the correlation between the yield of the cod fishery for one year and that of the herring fishery in the same and following years gives:

		for period 1909—27	for period 1912—27
Yield of cod fishery correlated with yield of net and pound-net herring fishery	same year.....	$r = -0.09$; $\sigma_r = 0.23$	$r = -0.19$; $\sigma_r = 0.24$
	1 year after....	$r = -0.42$; $\sigma_r = 0.19$	$r = -0.57$; $\sigma_r = 0.17$
	2 years after....	$r = -0.51$; $\sigma_r = 0.18$	$r = -0.66$; $\sigma_r = 0.15$
	3 years after....	$r = -0.43$; $\sigma_r = 0.20$	$r = -0.43$; $\sigma_r = 0.23$

The connexion between the yields of the two fisheries since 1912 is shown in Fig. 2.

e) The true Baltic. By calculating for this area the correlation coefficient between the yield of the cod fishery and that of the net and pound-net herring fishery we obtain:

		for period 1909—27	for period 1912—27
Yield of Danish cod fishery correlated with yield of net and pound-net herring fishery in the true Baltic	same year.....	$r = -0.39$; $\sigma_r = 0.19$	$r = -0.43$; $\sigma_r = 0.20$
	1 year after.....	$r = -0.24$; $\sigma_r = 0.22$	$r = -0.28$; $\sigma_r = 0.24$
	2 years after....	$r = -0.00$; $\sigma_r = 0.24$	$r = -0.13$; $\sigma_r = 0.27$
	3 years after....	$r = -0.14$; $\sigma_r = 0.24$	$r = -0.37$; $\sigma_r = 0.24$

We thus cannot establish for this area any connexion between the yield of the cod fishery and that of the net and pound-net herring fishery.

B. The cod fishery compared with the drift-net herring fishery.

We will now investigate whether the variations in the yield of the drift-net herring fishery show any demonstrable connexion with the variations in the cod fishery yield. The yield of the drift-net herring fishery is by reason of the shorter period (cp. p. 6) of considerably less value for this investigation than the yield of the net and pound-net herring fishery.

a) Kattegat and Belts. In these areas the drift-net herring fishery produced on an average considerably less weight of herring than the net and pound-net herring fishery. From Tables 1 and 2 it will be seen that the variations from year to year in the yields of both the cod and the drift-net herring fishery in these two areas follow a very similar course. The correlation coefficient between the yield of the cod fishery in the Kattegat and in the Belts during the period in question is $r = 0.82$; $\sigma_r = 0.08$, and the correlation coefficient between the yields of the drift-net herring fishery in the two areas is $r = 0.63$; $\sigma_r = 0.16$. If the fishery yields in the two areas are added together, the aggregate yield of the drift-net herring fishery is presumably a better expression for the size of the stock the drift-net fishery can reach than if each of the areas is taken alone.

By correlating the yield of the cod fishery with that of the drift-net herring fishery for the period 1909—27 (excluding 1914—18 in the case of the herring fishery) in these areas we obtain:

Yield of cod fishery correlated with yield of drift-net herring fishery in the Kattegat and the Belts	same year.....	$r = 0.10$; $\sigma_r = 0.26$
	1 year after.....	$r = 0.16$; $\sigma_r = 0.27$
	2 years after....	$r = 0.10$; $\sigma_r = 0.29$
	3 years after....	$r = 0.33$; $\sigma_r = 0.27$

It will be seen in the case of the Kattegat and the Belts no connexion can be perceived between the yield of the cod fishery and the drift-net herring fishery.

b) The Sound, the western Baltic, and the true Baltic. In these areas the yield of the drift-net herring fishery during the period here in question has been on an average as large as or larger than the yield of the net and pound-net herring fishery and may therefore be regarded as equally good or better than the latter as an expression for the size of the stock.

By calculating for these areas the correlation coefficient between the cod fishery and the drift-net herring fishery during the period 1909—27 (excluding 1914—18 in the case of the herring fishery), we obtain:

		Sound	W. Baltic	True Baltic
Yield of Danish cod fishery correlated with yield of Danish drift-net herring fishery	same year	$r = 0.52$; $\sigma_r = 0.19$	$r = -0.40$; $\sigma_r = 0.22$	$r = -0.42$; $\sigma_r = 0.22$
	1 year after.....	$r = -0.14$; $\sigma_r = 0.27$	$r = -0.40$; $\sigma_r = 0.23$	$r = -0.66$; $\sigma_r = 0.16$
	2 years after	$r = -0.52$; $\sigma_r = 0.21$	$r = -0.39$; $\sigma_r = 0.25$	$r = -0.59$; $\sigma_r = 0.19$
	3 years after	$r = -0.60$; $\sigma_r = 0.19$	$r = -0.77$; $\sigma_r = 0.12$	$r = -0.04$; $\sigma_r = 0.30$
	4 years after	$r = -0.47$; $\sigma_r = 0.25$	$r = -0.43$; $\sigma_r = 0.26$	$r = -0.10$; $\sigma_r = 0.31$

It will be seen that there is here no doubt a connexion, and that the interval of time between the yield of the cod fishery and that yield of the drift-net herring fishery which shows the greatest correlation with it seems to be about 1 year more than the interval of time between the yield of the cod fishery and that of the net and pound-net herring fishery varying in accordance with it, which was to be expected in view of the fact that the herring caught with the drift-nets are on an average older than those caught with the pound-nets.

C. Discussion of the results of the investigation.

The cause of the connexion between the two fishery yields is presumably that the cod stock reduces the contemporary herring stock. In opposition to the conditions which prevail for instance along the Norwegian coast, a certain year class of herring is never predominant in the fishery yield in these areas for more than 3—4 years at most and in distinctly decreasing quantities. That mainly a few definite age groups predominate in the stock which is the object of the fishery is a condition for the connexion between the cod and herring stocks proving so pronounced as it is in these areas, and is possibly caused by the cod stock reducing the herring stock.

The interval of 1—2 years, in part 3 years, found to elapse from the time when a certain cod stock is exploited by the fishery until the herring stock which is most affected by it becomes an object of the fishery can be explained naturally by the fact that the cod especially consume the small herring, according to Erik M. Poulsen herring of about 10, untill 15 cm. length, i. e. herring in their first and second years, whilst herring do not in the main become an object of fishing until their third or fourth years.

The causal connexion cannot be sought in the circumstance that hydrographical conditions simultaneously affect the tiny fry both of cod and of winter and spring herring, (the effect being however opposed for the fry of these two species), because in that case there would not be the phase-difference which has been found to exist between the variations in the yields of the two fisheries.

That a considerable correlation coefficient has also been revealed by most calculations between the yields of the cod and herring fisheries in the same year, and when the cod fishery yield is compared with the herring fishery yield more than 2—3 years later, is a necessary consequence of the size of the cod stock changing slowly from year to year and not abruptly.

According to A. C. Johansen and E. Neergaard Møller[1] the average weight of one cod or herring caught by Danish fishermen in the various areas is as follows:

	Kattegat	Belt Sea	True Baltic
Average weight of one cod	700 grm.	400 grm.	400 grm.
„ „ „ „ herring	125 „	75 „	37.5 „

[1] A. C. Johansen and E. Neergaard Møller: Biological-Statistical report of the Danish Sea-Fishery 1909. Medd. f. Komm. f. Havunders. Ser. Fiskeristatistik Bd. I. 1912.

The mean yields of the Danish cod and herring fisheries for the period 1909—27 converted into terms of numbers have consequently been:

In the Kattegat	c. 5.5 million cod	c. 28 million herring
In the Belts	„ 11.5 „ „	„ 77 „ „
In the true Baltic	„ 2 „ „	„ 88 „ „

If we reckon that in the course of one year the cod fishery in the Kattegat and the Belts captures one fifth of the stock of those sizes which are the object of the fishery and in the area where the fishery is carried on, we see that each cod in these size categories must consume 1 herring in the Kattegat and $1^1/_2$ herring in the Belts per year if the cod stock is to account for an equally large number of herring as the fishery. If in the case of the true Baltic we can reckon with 10 per cent. of these cod being captured in the course of one year each cod should consume $4^1/_2$ herring in this area in one year.

D. Other causes of the fluctuations in the yield of the herring fishery.

It is of very great interest that the yield of the herring fishery since 1927 has been on the increase despite the fact that the cod stock is still large. This shows that circumstances can arise which bring about a change in the dependance of the size of the herring stock on that of the cod stock. The reason for this is presumably to be found in good spawning years for herring, since we may suppose that in them so many herring may be produced that even a considerable cod stock is unable to prevent a large herring stock from coming into existence. Conversely, we must not expect that a small cod stock will invariably be followed by a large herring stock, since poor spawning years for herring can also keep down the size of the herring stock to small numbers.

With respect to the Bornholm herring fishery I have shown on a previous occasion that an essential contributory factor in the variations of this fishery yield is a fluctuation with a period of 3.7 years. This is presumably due to the fact that a large stock of spawning herring again produce a large stock of spawning herring some years later (averagely 3.7 years)[1].

III. Causes of the fluctuations from year to year in the yield of the cod fishery.

As appears from the foregoing, the cause of the variations from year to year in the yield of the herring fishery is to a large extent to be found in the variations in the size of the cod stock. It is therefore doubly interesting to seek to determine the causes of the fluctuations from year to year in the yield of the cod fishery.

It has been pointed out above (p. 4) that these variations cannot be ascribed to the variations in the intensity of fishing.

Amongst the causes of the fluctuations in the size of the stock two may especially be regarded as of considerable consequence, viz. 1) variations in the quantity of fry, and 2) variations in the autumn or winter immigration of large cod from the Skagerak.

If the variations in the production of fry depends on certain hydrographical factors and if it is the quantity of fry which is one of the principal causes of the variations in the size of the cod stock and thereby of the variations in the total yield of the cod fishery, then there must be a demonstrable correlation between these hydrographical conditions and the fishery yield three, four, or five years later, let us say four years as a mean since the captured cod are of about this age on an average.

[1] Aage J. C. Jensen: On the Influence of the Quantity of spawning Herrings upon the Stock of the following years. — Journal du Conseil Vol. II. No. 1. 1927.

Of the hydrographical factors which may be taken as influencing the quantity of fry, the first and foremost in these areas are temperature and salinity. By calculating the correlation coefficient between the total yield of the cod fishery in the Kattegat and the Belts during the years 1909—27 and the surface temperature and salinity at Schultz' Grund light-vessel during the months March—September four years previously we obtain:

			March	April	May	June	July	Aug.
Total yield of cod fishery correlated with salinity and temperature, Schultz' Grund, 0 m., 4 years previously	Salinity	r	0.00	0.33	0.05	0.59	0.29	0.29
		σ_r	0.23	0.21	0.23	0.15	0.21	0.21
	Temperature	r	— 0.12	0.03	0.11	— 0.17	— 0.40	— 0.39
		σ_r	0.23	0.23	0.23	0.22	0.19	0.19

It will be seen that between the yield of the cod fishery and the salinity in June there is a correlation coefficient greater than three times σ_r. As is well-known, the hydrographical conditions in the surface water in summer depend on the inflow into the bottom layer in the spring[1] and the connexion found can therefore possibly be indirect. By comparing the total yield of the cod fishery in the Kattegat and the Belts with the salinity and temperature at Schultz' Grund light-vessel on the bottom (26 m.) four years previously we obtain:

			March	April	May	June	July	Aug.
Total yield of cod fishery correlated with salinity and temperature, Schultz' Grund, at bottom, 4 years previously	Salinity	r	0.08	0.32	0.21	— 0.22	— 0.57	0.06
		σ_r	0.23	0.20	0.22	0.22	0.17	0.23
	Temperature...	r	0.17	0.67	0.63	0.66	0.57	— 0.04
		σ_r	0.23	0.13	0.14	0.13	0.15	0.23

A genuine connexion between the yield of the cod fishery in the above-mentioned areas and the temperature in the lower water layer can be established for the months from April till June, i. e. until no more pelagic cod fry of any importance are to be found in these areas. A contributory cause of there being such a large correlation coefficient between the yield of the cod fishery and the bottom temperature also in the summer months proper may be the fact that there is a considerable positive correlation between the bottom temperature in the spring months and the ensuing summer months.

As is well-known from fishing experiments for cod fry, the largest numbers of fry are found in the lowest water layer and it is a reasonable conjecture that it is especially the temperature prevailing in this water layer that influences the production of fry.

If we summarize the effect of the temperature during these four months, which we can do to a certain extent by taking the mean temperature of the four months, and calculate the correlation coefficient between this mean temperature for the various years and the cod fishery yield four years later, we obtain $r = 0.84$; $\sigma_r = 0.07$.

As mentioned above, (see p. 6) the statistics from the years subsequent to 1912 are without any doubt more accurate than those of former years. If we take the cod fishery yield only for the years subsequent to 1912 and correlate it with the mean temperature at Schultz' Grund, at 26 m., during the months April—July four years previously, we obtain $r = 0.70$; $\sigma_r = 0.13$.

Since the stock which in any one year is the object of fishing is derived from several spawning years it is of interest to correlate the cod fishery yield with the mean temperature at Schultz' Grund, at the bottom, 3, 4, and 5 years previously. A calculation of the correlation between the fishery yield in the Kattegat and the Belt Sea and this mean temperature gives for the period 1912—27: $r = 0.75$; $\sigma_r = 0.12$.

As in March there are considerable quantities of pelagic cod fry in these areas it is reasonable to suppose that also the temperature in this month, despite the low correlation coefficient found by the calculation, will prove to exert an influence on the quantity of fry and thereby on the size of the cod

[1] A. C. Johansen and Aage J. C. Jensen: Remarks on the Influence of the Currents in the Waters about Denmark upon the Climate of Denmark and neighbouring countries. — Physiological Papers dedicated to Professor August Krogh. Copenhagen 1926.

stock, upon which fishery has been carried on 3, 4, and 5 years later. If we take the means of the temperatures at Schultz' Grund, at the bottom for March, April, and May and correlate these mean figures with the cod fishery yield 4 years later we obtain for the period 1912—27: $r = 0.44$; $\sigma_r = 0.20$. We can then add the effect of the temperature for 3 years in these months in such a way that for instance the temperature 4 years previously is taken to have an effect on the size of the stock which is the object of the fishery three times greater than that of the temperature 3 and 5 years previously. The correlation

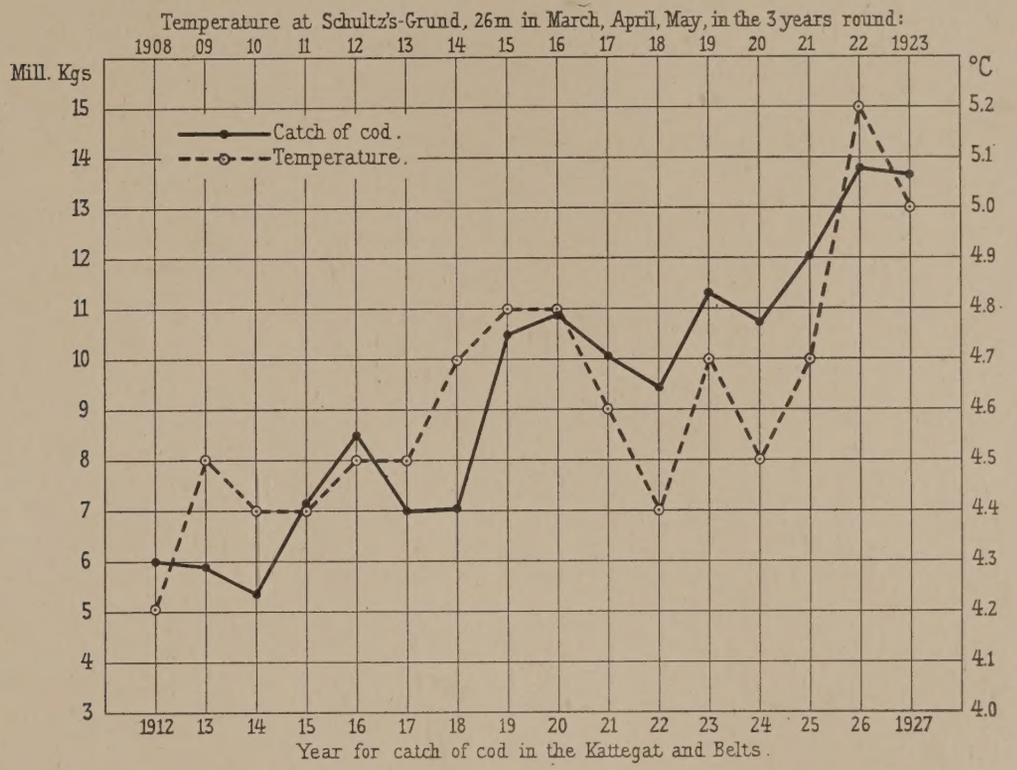

Fig. 3. Average bottom-temperature at Schultz's Grund in March, April, May in each of the three-year periods 1908—23 (see Text) compared with yield of the cod fishery in Kattegat and Belts in 1912—27 respectively.

between the values thereby found for the temperature and the cod fishery yield after the above-mentioned interval of time then gives for the period 1912—27: $r = 0.80$; $\sigma_r = 0.09$. This connexion is shown in Fig. 3.

We can here assume, as in the case of the connexion between the cod and the herring fishery yields shown in Fig. 1, that an important reason for the correlation coefficients having such large values is the uniform great changes in the main features of the two curves, in this particular case an increase. A rise in temperature throughout a period such as this can obviously occur simultaneously with the increase of a fishery yield without there consequently being any causal connexion between the fishery yield and the temperature. We will therefore for the April temperature at Schultz' Grund, at the bottom, reckon with a straight line increase in the temperature from 3.2° in 1905 to 5.2° in 1923, and with a straight line increase in the cod fishery yield in the two areas from 4 million kg. in 1909 to 13 million kg. in 1927. The temperature and catch anomalies are thereupon calculated from these normal curves which

pass uniformly through the two sets of observed values. A calculation of the correlation between the two sets of anomalies in the years 1909—27 gives: $r = 0.50$; $\sigma_r = 0.17$, i. e. a value for r which is three times greater than σ_r. This shows that it is not only in the main features but also in the details that the temperature and the cod fishery yield follow such a similar course that we are justified in assuming that there is a causal connexion between them.

In the case of the true Baltic, the changes in the hydrographical conditions in the deeper intermediate water layers, where the eggs and pelagic fry of the cod are found, cannot unfortunately be traced from year to year, because of the observations carried out continuously year after year during the periods here in question we only possess records of temperature and salinity of the surface water.

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